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VIBRATION ANALYSIS OF GAS TURBINE'S TRANSPORTATION CARRIGAGE AND WARRANTY ISSUES



TECVIB
E N G E N H A R I A



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Wiriton is the founder of Tecvib Engineering a well-recognized consultant nationwide, building up to 45 years' experience in vibration analysis and troubleshooting.



ABSTRACT

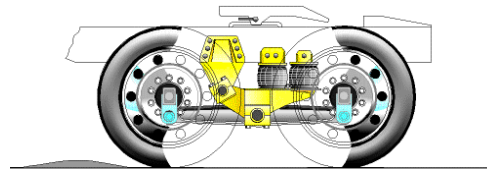
This paper describes the investigation of whether the vibration shock limits were exceeded on the transportation of 2 gas turbines.

This investigation was requested due to an improper suspension type of the carriage used in the transport and the OEM consideration if vibration limits were exceeded during the route. It ultimately lead to a contractual impasse where the OEM required full bearing inspection prior to commissioning as a prerequisite to maintain the warranty on the equipment which the client did not agree to follow without further investigation.



Warranty issues due to contrariety of OEMs transport requests

- A large Brazilian petrochemical company acquired 2 new gas turbines of 24MW power output.
- Transport between the port of delivery and the installation shipyard were carried out in one vehicle with multi type leaf spring conventional suspensions
- ❖ The procedure required the turbine should be housed for transportation in an appropriate Engine Shipping Containers, and that ground transportation must be performed on fully air-suspended vehicles/carriages.



Problem statement - Justification

As the second requirement was not obeyed, the OEM required the turbines to be returned for bearing inspections prior to commissioning

OEM also informed that if these inspections were not carried out, the equipment warranty would be suspended.

- ❖ It was decided to evaluate the dynamic behavior of the container vibrations during the carriage en-route between the Port and the Shipyard to verify if the vibration limit established by the OEM was really exceeded and with what frequency and intensity this occurred.



Problem statement - Proposal

The job proposal was basically to recreate the same scenario of transportation that the turbines were subjected to.

And monitor the shocks and vibrations on specific points of the truck carriage.

Resources

- 01 Consultant Engineer.
- 01 multichannel vibration analyzer with 20 channels and 120 dB dynamic range;
- 12 accelerometers (100 mV/g) with long cables, connectors and magnetic bases.
- 01 Toshiba notebook with software for capture, storage and data processing for the dynamic signals.



Problem statement - Proposal

Boundary conditions (Truck)

- ✓ Same driver
- ✓ Same truck
- ✓ Same route
- ✓ Same time of the day
- ✓ Same speeds (Follow tacograph disk records)



Boundary conditions (Load)

- ✓ Same equivalente mass counterweights
- ✓ Same center of gravity alocation of cargo

Mass turbine+container: 11,000 kg

Total mass (02 units): 22,000 kg



OEMs Criteria

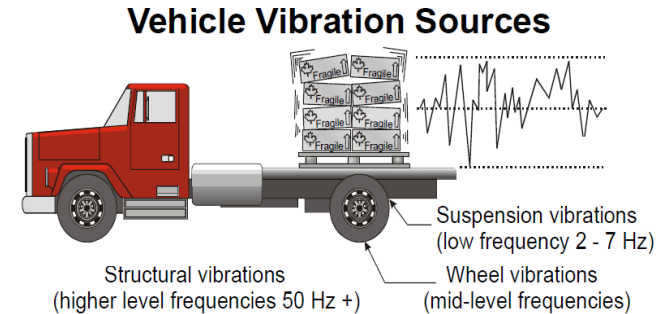
- ❖ The maximum allowable loads for the container are 3.5 g vertically up, 2.5 g vertically down, 2.0 g forward and back (axial), and 1.5 g laterally (horizontal)
- ❖ The maximum permissible sustained vibration or repetitive impact load on a non-operational gas turbine or container is 0.5 g at any frequency, in either direction. Exceeding this limit could damage the equipment



Literature review

❖ Literature on the subject is limited. Few sources state that:

- ✓ Main sources of impacts occur in accidental falls during the drive, abrupt brakes and vehicle passages over holes in the runways, speedbumps and railroad crossings.
- ✓ Most vibration damage occurs in the range of 3 to 30 Hertz
- ✓ *Ramakrishnan, A., & Pecht, M. (2004). Load characterization during transportation. Microelectronics Reliability, 44(2), 333-338.*



Said that 580 Hz maximum spectrum frequency is sufficiently high for road vibrations

Literature review

❖ Few sources have investigated truck vibrations during transportation of art:

- ✓ *Saunders, D., et al. 1991. Soft pack – the soft option? In Art in transit: studies in the transport of paintings, ed. M.F. Mecklenburg, 311–321. Washington, DC: National Gallery of Art.*
 - States that the relevant continuous vibration frequency range is between 50.0 and 500 Hz
- ✓ *Marcon, PG., ‘Shock, vibration and the shipping environment’, in Art in Transit: Studies in the Transport of Paintings, ed. M.F. Mecklenburg, National Gallery of Art, Washington (1991) 121-132.*
 - Has said the relevant range is between 2.5 and 100 Hz.



Test set-ups – Sensors placed on truck carriage structure

- Frequency scale background: 1000 Hz
- Number of spectral lines: 3200
- Acquisition time: 3.2 seconds
- Sample rate: 2560 samples / second
- Cut-off frequency high pass: 0.1 Hz



Analyzer Channel	Sensor	Measured Parameter	Measurement Point
1	1H-D	Vibration Acceleration	Point 1 Horiz. right side
2	1V-D	Vibration Acceleration	Point 1 Vert. right side
3	1A-D	Vibration Acceleration	Point 1 Axial right side
4	1H-E	Vibration Acceleration	Point 1 Horiz. left side
5	1V-E	Vibration Acceleration	Point 1 Vert. left side
6	2H-D	Vibration Acceleration	Point 2 Horiz. right side
7	2V-D	Vibration Acceleration	Point 2 Vert. right side
8	2H-E	Vibration Acceleration	Point 2 Horiz. left side
9	2V-E	Vibration Acceleration	Point 2 Vert. left side
10	3H-D	Vibration Acceleration	Point 3 Horiz. right side
11	3V-D	Vibration Acceleration	Point 3 Vert. right side
12	3A-D	Vibration Acceleration	Point 3 Axial right side

- Frequency range background: 200 Hz
- Number of spectral lines: 1600
- Acquisition time: 8.0 seconds
- Sample rate: 512 samples / second
- Cut-off frequency high pass: 0.1 Hz

Test results

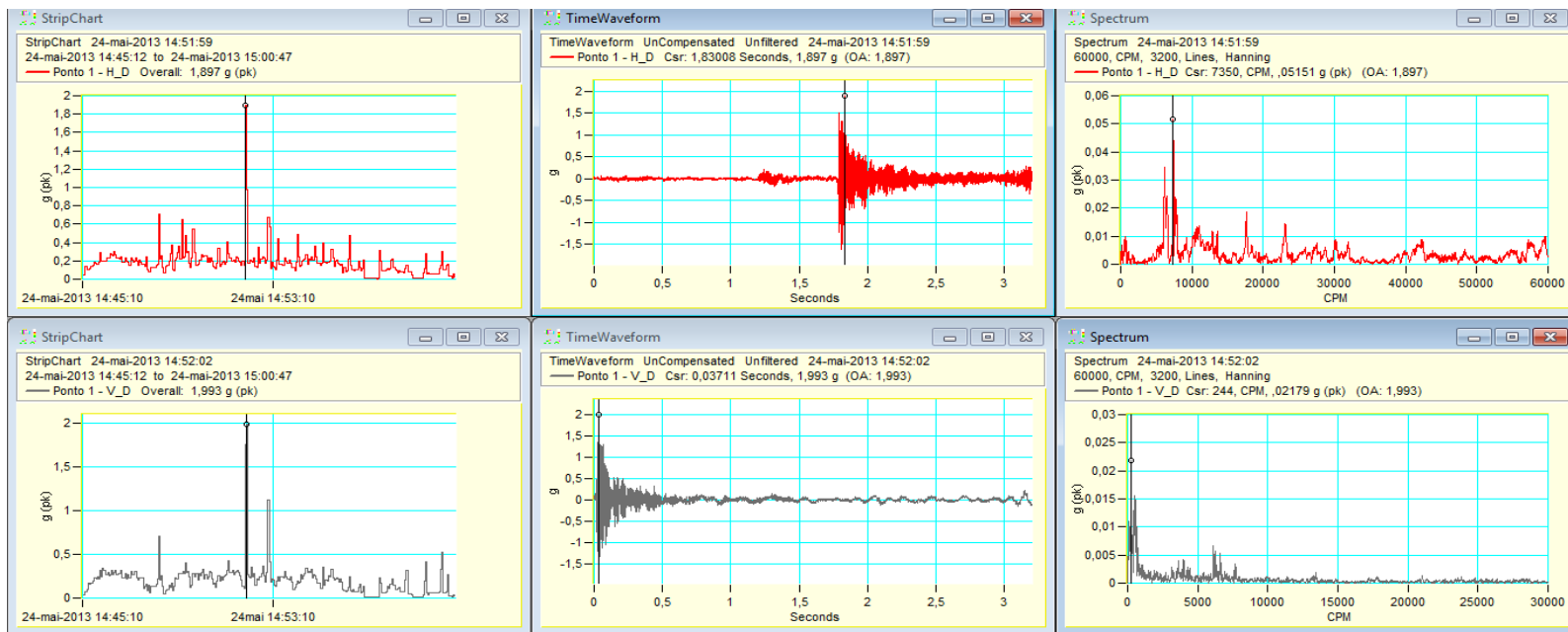
Main occurrences during the journey were recorded for both tests:

le.:

- Railroad crossing: 14h47m48s;
- Passages on speed bumps: 14h48m40s, 14h50m39s, 14h51m46s, 14h52m24s, 14h52m50s, 14h53m12s, 14h54m07s, 14h47m48s, 14h55m04s and 14h56m02s;
- Depression on the road: 14h49m15s and 14h49m38s;
- Brakes at the entrance of the Shipyard: 14h56m50s and 14h58m30s



Test results



Trends, waveforms and spectra of the vibration acceleration of the truck container during tested route, with frequency range of 1000 Hz. Maximum amplitude on points 1HD 1.90 g-pk and 1VD 1.99 g-pk.



Summary results

- ✓ Vibration acceleration levels during transport simulations of the containers exceeded the limits established by the OEM, but this was only true for 1000Hz frequency range measurements;
- ✓ For measurements with 200 Hz frequency range, all measurements were well below the limits recommended by the OEM.

MEASUREMENT POINT/ DIRECTION		VIBRATION ACCELERATION (g-peak) MONITORING OF THE TRUCKS' CARRIAGE DURING TRANSIT FROM THE PORT TO THE SHIPYARD. SIMULATED CONDITION WITH COUNTERWEIGHTS WITH EQUIVALENT MASS AND DISTRIBUTION ACROSS THE CARRIAGE. (g-pico)						
		200Hz, 1600 lines, Acquisition time 8 seconds			1000Hz, 3200 lines, Acquisition time 3,2 seconds			Recommended limits by OEM (g)
		Max overall	(+) Peaks	(-) Peaks	Max overall	(+) Peaks	(-) Peaks	
Truck's right side	1HD	0,27	0,19	-0,27	1,9	1,9	-1,61	1,5
	1VD	0,42	0,42	-0,33	1,99	1,99	-1,6	3,5 / -2,5
	1AD	0,21	0,21	-0,12	1,37	1,34	-1,37	2
Truck's left side	1HE	0,27	0,26	-0,22	1,25	1,25	-1,15	1,5
	1VE	0,44	0,44	-0,32	1,84	1,48	-1,84	3,5 / -2,5
Truck's right side	2HD	0,3	0,26	-0,3	0,91	0,91	-0,79	1,5
	2VD	0,74	0,52	-0,74	1,76	1,76	-1,36	3,5 / -2,5
Truck's left side	2HE	0,29	0,26	-0,29	1,06	1,06	-1	1,5
	2VE	0,75	0,56	-0,75	1,65	1,65	-1,18	3,5 / -2,5
Truck's right side	3HD	0,61	0,4	-0,61	0,75	0,75	-0,62	1,5
	3VD	0,38	0,38	-0,31	0,78	0,78	-0,59	3,5 / -2,5
	3AD	0,17	0,17	-0,12	1,21	0,94	-1,21	2



Conclusions and Recommendations

- Low risk of damage to the turbine bearings due to the transportation between the Port and the Shipyard
- Our recommendation to the machine operator was to negotiate the warranty without having to perform the bearings inspections
- Vibration analysis of the machine start-up and load setting

- ❖ Based on our recommendations, the OEM agreed to only keep the warranty of the bearings but not of the whole machine, which both Tecvib and the machine operator agreed.
- ❖ Upon turbine start-up, vibration analysis showed no issues whatsoever and the OEM's warranty were established back into normal terms.



Lessons Learned

- There is not a wide amount of literature and research on this matter
- Some OEMs internal procedures can appear a bit vague in terms of frequency band criteria for vibration acceleration limits
- There are means to negotiate warranty terms between OEM and client in a friendly way and with technical based arguments
- The monitoring of impacts on the transportation of these equipments should be adopted as a standard procedure
 - Portable, low-cost MEMS based accelerometers (Ie.: Droptag) are the ideal way to keep track of the dynamics involved during transportation of sensitive cargo.



Acknowledgments



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